ECE 4391 Electromagnetic Compatibility Quiz 3
### July 12, 2004

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Instructions. Work the quiz on the blank sheets provided. Do not write your work or answers on this question sheet. Print your name in the space above and at the top of all other pages in your quiz. Be brief with your answers. Draw simple diagrams that illustrate your answers. The quiz is closed book and closed notes. **Honor Code Statements:** *I have neither given nor received help on this quiz.* Initials _____

1. (a) The circuit shows an *RLC* filter. Use voltage division to solve for the voltage gain V_o/V_i as a function of R, X_L, and X_C.
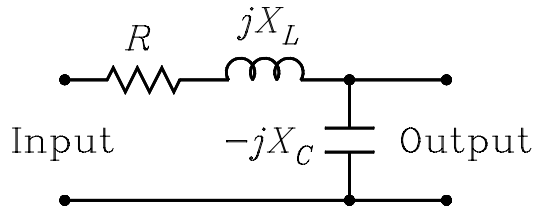
$$\frac{V_o}{V_i} = \frac{-jX_C}{R + j(X_L - X_C)}$$

(b) The inductor is realized by a primarily inductive ferrite bead whose reactance is labeled "Bead 2" in the figure. Solve for the value of the capacitor such that the resonance frequency of the circuit is $f_0 = 60\,\text{MHz}$, i.e. the frequency at which $X_L = X_C$.
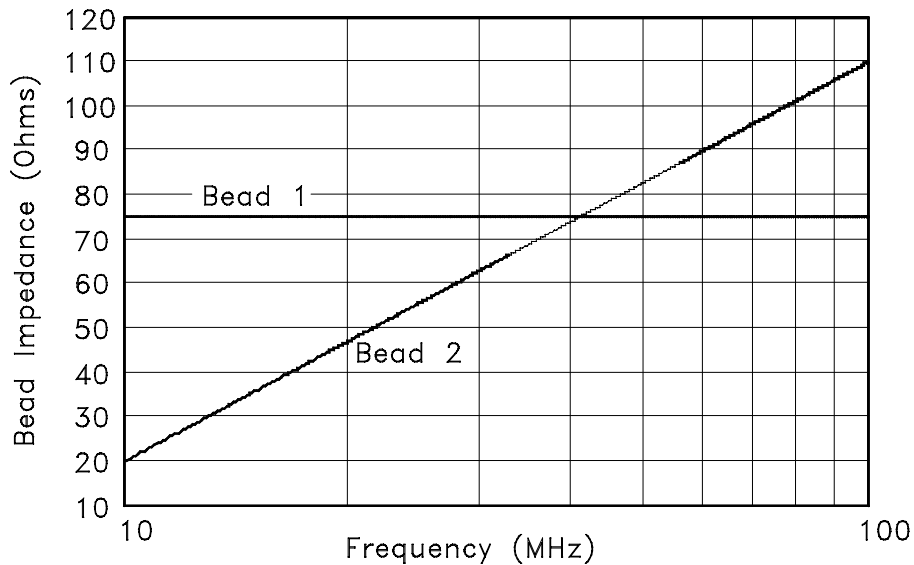
$$X_C = X_L = 90 \implies \frac{1}{2\pi fC} = 90 \implies C = \frac{1}{2\pi f \times 90} = 29.5\,\text{pF}$$

(c) One standard-form of the voltage gain transfer function for the filter is

$$\frac{V_o}{V_i} = \frac{1}{(s/\omega_0)^2 + 2\zeta(s/\omega_0) + 1}$$

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where $s = j\omega$, $\omega_0 = 2\pi f_0$ is the radian resonance frequency, and ζ is the damping factor. If the resistor in the circuit is realized by a primarily resistive ferrite bead whose resistance is labeled "Bead 1" in the figure, solve for the numerical value of the damping factor ζ. Hint, equate the expression found in part (a) to the standard form expression and let $f = f_0$.

$$s = j\omega_0 \qquad X_C = X_L \Longrightarrow \frac{1}{2\zeta j} = \frac{-jX_C}{R} = \frac{-jX_L}{R} \Longrightarrow \zeta = \frac{R}{2X_L} = 0.417$$

2. (a) A copper conductor has a rectangular cross section of 0.4×2.5 cm. The resistivity of copper is $\rho = 1.724 \times 10^{-6}\,\Omega\,\text{cm}$. Calculate the resistance per $100\,\text{ft}$ of conductor length.

$$R = \frac{1.724 \times 10^{-6} \times 2.54 \times 12 \times 100}{0.75 \times 1.5} = 4.67\,\text{m}\Omega$$

(b) What causes the resistance of a conductor to increase as the frequency is increased? *As frequency is increased, the currents tend to flow on the surface of the conductor rather than being uniformly distributed over the cross-section of the conductor. This causes the resistance to increase. It is called the skin effect.*

3. A balanced amplifier that is slightly "out of balance" has an output voltage that is given by $v_o = 101v_{i1} - 100v_{i2}$. The input voltages are

$$\begin{aligned} v_{i1} &= 0.02\sin\omega_1 t + 0.1\sin\omega_2 t \\ v_{i2} &= -0.02\sin\omega_1 t + 0.1\sin\omega_2 t \end{aligned}$$

where the ω_1 term is a desired differential signal and the ω_2 term is an undesired common-mode interference signal, e.g. a $60\,\text{Hz}$ hum.

(a) The differential input voltage is defined by $v_{id} = v_{i1} - v_{i2}$. The common-mode input voltage is defined by $v_{icm} = (v_{i1} + v_{i2})/2$. Calculate the differential and common-mode voltages at the input.

$$v_{id} = 0.04\sin\omega_1 t \qquad v_{icm} = 0.1\sin\omega_2 t$$

(b) Calculate the output voltage.

$$v_o = 4.02\sin\omega_1 t + 0.1\sin\omega_2 t$$

(c) What is the dB improvement in the signal-to-noise ratio at the amplifier output compared to its value at the input? Consider the desired input signal to be the differential component and the undesired input noise to be the common-mode component.

$$\begin{aligned} SNR_i &= 20\log\frac{0.04}{0.1} = -7.96\,\text{dB} \\ SNR_o &= 20\log\frac{4.02}{0.1} = 32.08\,\text{dB} \\ \Delta SNR &= 32.08 - (-7.96) = 40.04\,\text{dB} \end{aligned}$$

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4. (a) At a circuit, what is used to minimize the effect of the parasitic impedance of external power-supply leads? *Add a power supply decoupling capacitor from the power supply lead to ground at the point where the lead connects to the circuit. See Figure 4-17.* (b) How is undesirable feedback on the power supply leads between stages of a high-gain amplifier prevented? *Isolate the stages with RC low-pass filters which the author referrs to as feedback decoupling networks. See Figure 4-17.* (c) Why should the characteristic impedance of a power distribution transmission line be as low as possible? *The dc voltage drop in the power supply lead is determined by its dc resistance. If the load current changes changes instantaneously, e.g. when a logic gate changes states, the load voltage drop decreases by an amount $\Delta V_L = \Delta I_L \times Z_0$. To minimize this, Z_0 should be as small as possible.* (d) What geometry line has the lowest characteristic impedance? *Rectangular conductors spaced as close as possible to each other. See the example in Figure 4-11.*

5. (a) What type of capacitors have the highest capacitance to volume ratio and what frequency range are they most useful in? *Electrolytic capacitors. They are best for low frequencies.* (b) What are two types of capacitors that are best at high frequencies? *Mica and ceramic.* (c) What can be used to reduce the capacitance coupling between the windings of a transformer? *Add a grounded electrostatic shield between the two windings. See Figure 5-11.* (d) What type of interference is an inductor susceptible to picking up and how is it minimized? *Magnetic field interference. It can be minimized by not using air core inductors, by surrounding the inductor with a magnetic shield, and by changing the orientation of the inductor.*